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1855-1930

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1859-1951

September 15, 2000

Attorney Docket No.: 06618/512001/CIT3076

**Box Patent Application**  
Commissioner for Patents  
Washington, DC 20231

Presented for filing is a new patent application claiming priority from a provisional patent application of:

Applicant: MORY GHARIB, DOMINIQUE FOURGUETTE, DARIUS  
MODARRESS, SIAMAK FOROUHAR, AND FREDERIC  
TAUGWALDER

Title: INTEGRATED SENSOR

Enclosed are the following papers, including those required to receive a filing date under 37 CFR 1.53(b):

	Pages
Specification	10
Claims	9
Abstract	1
Declaration	[To be Filed at a Later Date]
Drawing(s)	7

Enclosures:  
— Postcard.

There are 37 total claims, 7 of which are independent.

Small entity status established in the parent case is still proper and desired.

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September 15, 2000  
Page 2

Under 35 USC §119(e)(1), this application claims the benefit of prior U.S. provisional application 30/154,487, filed September 17, 1999.

Basic filing fee	\$0
Total claims in excess of 20 times \$9	\$0
Independent claims in excess of 3 times \$39	\$0
Fee for multiple dependent claims	\$0
Total filing fee:	\$0


No filing fee is being paid at this time. If this application is found to be incomplete, or if a telephone conference would otherwise be helpful, please call the undersigned at (858) 678-5070.

Kindly acknowledge receipt of this application by returning the enclosed postcard.

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Respectfully submitted,

  
Scott C. Harris  
Reg. No. 32,030  
Enclosures  
SCH/rpi  
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APPLICATION  
FOR  
UNITED STATES LETTERS PATENT

TITLE: INTEGRATED SENSOR

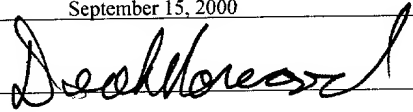
APPLICANT: MORTEZA GHARIB, DOMINIQUE FOURGUETTE,  
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## **INTEGRATED SENSORS**

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. Provisional  
5 application no. 60/154,486, and 60/154,487, both filed  
September 17, 1999.

### STATEMENT AS TO FEDERALLY-SPONSORED RESEARCH

The invention described herein was made in the  
performance of work under a NASA contract, and is subject  
10 to the provisions of Public Law 96-517 (U.S.C. 202) in  
which the contractor has elected to retain title.

### BACKGROUND

It is often desirable to obtain different kinds of  
15 information about particles.

One kind of information is about shear stress. An  
existing method of detecting wall shear stress puts a  
heated wire or element in the flow to be detected. The  
rate of cooling of the element provides a measure of the  
20 wall shear stress. Other similar sensors, which sense other  
parameters, are also known.

However, this system by itself has certain problems.  
The techniques may be intrusive, meaning that they may  
effect the rate of flow. The techniques can be affected by

contaminants in the flow. For example, certain  
contaminants may deposit on the heated element and cause  
the heated element to react differently. These techniques  
can also change the characteristics of the sensor; hence  
5 requiring calibration.

Non-intrusive optical techniques may be considered  
using conventional optics. However, this results in a  
bulky setup, and setup that is highly susceptible to  
vibration. Moreover, the size of such a setup may cause  
10 difficulty in allowing the system to be effectively used.

Other kinds of probes can be used to detect the size  
of particles, and may have similar drawbacks.

### SUMMARY

15 The present application teaches integrated optical  
sensors for detecting particle details.

One aspect detects and/or measures wall shear stress  
in flows.

### BRIEF DESCRIPTION OF THE DRAWINGS

20 These and other aspects will now be described in  
detail with reference to the accompanying drawings wherein:

Figure 1 shows a schematic for a first wall stress  
sensor;

Figure 2 shows an optical fringe pattern emitted by the sensor of Figure 1;

Figure 3 shows a details of fabrication of the optical part;

5 Figure 4 shows an assembly drawing showing the way in which the elements are held within a housing;

Figure 5 shows another embodiment using a ...

Figure 6...

10

# DETAILED DESCRIPTION

15

20

The present application teaches a special miniaturized and integrated optical sensor probe for measuring wall shear stress in aerodynamic and hydrodynamic flows for example. As described herein, the system also provides structure which is highly minaturizable, and which can be formed within a housing of a special type that enables the use of the sensor in harsh environments. Moreover, the system in is non-intrusive and non-invasive. The center of the probe's volume may be located very close to the surface being measured, e.g. as close as 100 microns to the surface. Moreover, the sensor as described herein may be configured in a way, as described herein, that may require less calibration.

A schematic of the sensor is shown in Figure 1. A diode laser 100 is formed on a substrate 102. The diode laser produces a diverging output beam 105 which diverges at a specified angle. The output beam is shaped, for example, into two, parallel very high aspect ratio ellipses. The beam is coupled toward a transparent substrate, e.g., a quartz substrate 110 which forms an optical assembly. The quartz substrate may have a size, for example, of 600 microns thick and 700 microns square on a side. The quartz substrate 110 includes a metal film 115 formed thereon, e.g., a film formed of chromium or aluminum. The metal film is processed to form specified openings therein. Optical slits are formed in an area 120 of the metal film, arranged to form a diffractive optical element. The slits can be fabricated by etching the metal from the thin film in a specified pattern.

The light exiting from the diffractive optical element 120 forms a two-dimensional, linearly diverging optical fringe pattern 125. The optical fringe pattern can, for example, simply include diverging fringes. The fringe pattern may be of the type shown in Figure 2 where the pattern width is on the order of 25 microns, and the position is on the order of 90 microns for the main part of

the fringe, with the edges of the fringe ending at 130 -  
140 microns.

The fringe 125 impinges on a mask 130 which is formed  
on the second surface 128 of the quartz substrate 110.

5 The second surface 128 of the quartz substrate is  
placed near the flow to be measured. Light is scattered  
off the particles crossing the fringe pattern to form  
reflected beam 130.

Scattered light is also obtained by a second optical  
10 window 135 that is formed in the metal film 115. The light  
is collected through that optical window, via another  
diffractive optical element 140 formed on the surface of  
the quartz element. The scattered light is collected by  
those elements and focused onto an optical fiber detector  
15 145. An avalanche photodiode 150 can be located at the end  
of the detector, receiving the light therefrom.

An important feature of system in Figure 1 is that the  
sensor element can be fabricated using micro-fabrication  
technology. The substrate 110 can be formed as shown in  
20 Figure 3. The surface 112 includes the laser "lens" 120,  
and the collection lens 130, 140. The other side 128 of  
the substrate includes a plurality of slits. In addition,  
both sides of the substrates include alignment marks. 112  
include the alignment marks 312, 314, which are alignment



marks for the electronic beams. The front side 128 includes the alignment marks 316, 318 which are the alignment for the front-to-back transfer.

The substrate may be fabricated as follows. A quartz  
5 substrate of size 2mm x 2mm x 0.5mm is obtained. The quartz substrate can be fused silica, for example. The substrate is first evaporatively coated with a thin film of chromium using evaporation. The result in structure is then coated with polymethylmetachrylate or PMMA.

10 Slits 130 are opened in the front side 128. This can be formed as two different openings, e.g., a first window 320 which is 100 microns wide and 500 microns long. A plurality of slits 325 are formed to the side of that window. These can be 1 - 2 microns wide, and 500 microns  
15 long. The slits have 10 micron separations from one another, and may be separated by 5 microns from the window 320. The slits and optical window pattern can be opened in the PMMA using e-beam lithography. The chromium may be subsequently wet edged in the open areas to form better  
20 openings.

Thereafter, the surface is coated with a thick layer of photoresist in order to protect the surface. The back side 112 is also coated with photoresist. The front side alignment marks are used to form front side holes and open

holes in the photoresist using an optical mask and UV exposure. The surface is then coated with metal for liftoff. The metal is removed using E-beam alignment marks. All of the photoresist can also be removed.

5 A PMMA layer is then deposited on the bottom of substrate 112. Two different diffractive optical elements are formed in the PMMA layer. The PMMA laser lens 120 is formed which is 200 microns wide 500 microns long. The PMMA collection lens 135 is formed that is 400 microns wide  
10 500 microns long. These are formed using E-beam lithography and developed using acetone.

The sensing element is then formed and mounted in a housing 400. The housing 400 includes all of the structure therein, including the diode laser and optical receiver.

15 This system can produce significant advantages. In addition, modifications in this system are contemplated. For example, a diffractive optical element can be used in place of the optical window 320 in order to collect the scattered light more efficiently.

20 In another embodiment, shown in Figure 5, the detector is mounted directly on the substrate 102. This avoids the use of fibers, and reduces the parts count. In this embodiment, both the laser 100, and photodiode 500 are mounted on a single substrate 102. A controller 502 may

also be mounted on the substrate. The controller may control both the laser 100 and the photodiode 500. For example, the controller can instruct the laser what and when to emit. It can receive information from the  
5 photodiode, and interpret it in view of timing information sent to the laser.

Another embodiment which forms a fiber optic particle probe is shown in Figures 6a and 6b. A diode laser is used along with curved gratings and detectors. Figure 6A shows  
10 a configuration with a laser 600 emitting along both sides 602 and 604. The two-sided emission provides laser output arms 606, 608. Beam 606 is reflected by mirrors 612, 614, and coupled to a curved grating 616. Beam 608 is correspondingly coupled to grating 618. The outputs 622,  
15 624 of gratings 616, 618 are recombined off the surface at a point 610. The point 610, for example, can be 3 millimeters over the surface of the substrate 600. A fringe pattern is formed by the recombination.

The fringe pattern is centered on a second laser beam,  
20 called the IMAX beam, that has been created by a second laser source 635. The IMAX beam provides information on the size of the particle and as such is a particle-sizing beam 620.

Light is scattered by the particles and received by photodetectors 642, 644, which are mounted on the substrates in locations to receive the scattered light from the particles at the point 610. The phase shift of the detectors is proportional to the particle size at the point 610. An on-chip or off processor or controller may receive the signals from the photodetectors and calculate the particle size.

Figure 6B shows an alternative embodiment in which fringes in space are formed. A single ended diode 650 produces an output 652. The diode laser output 652 is allowed to diverge onto a curved grating 654, which is blocked in its center shown as 656.

The grating redirects the light 652 into two separated light beams 660, 662, which are separated by the blocked portion 656. The two light beams to intersect 3 millimeters off the surface at the point 664. A separate laser 668 produces an IMAX beam 670. As in the Figure 6A embodiment, photodetectors 680, 682 detect the scattered light and use the scattered light to find particle size.

Another embodiment shown in Figure 7 uses a phased Doppler technique without the technique using the IMAX beam. The same structure of the laser 650 and curved grating 654 forming the LDA beams intersecting above the

surface is defined. Detectors 700, 710 are located on an arm extending above the surface to receive the beam. This technique works best for particle sizes close to the laser wavelength.

5       As in the other embodiments, the scattered light gathered by the two detectors exhibits a phase shift that is proportional to the phase particle size.

          Although only a few embodiments have been defined in detail above, other modifications are possible.

10

What is claimed is:

1. A sensor, comprising;  
a laser element, producing a diverging beam; and  
a single substrate, including a first diffractive

5 optical element placed to receive the diverging beam and  
produce a fringe based thereon, a scattering element which  
scatters said fringe beam based on particles being  
detected, and a second diffractive element receiving  
scattered light.

10

2. A sensor as in claim 1, wherein said single  
substrate includes a first surface which includes both said  
first and second diffractive optical elements.

15

3. A sensor as in claim 2, further comprising a  
second surface, opposite said first surface, including a  
pattern formed thereon which receives particles crossing  
the pattern, and light crossing the particles being  
collected as said scattered light.

20

4. A sensor as in claim 1, further comprising a  
detector, receiving said scattered light, and producing a  
signal indicative thereof.

5. A sensor as in claim 4, further comprising a housing, wherein said laser element, said single substrate, and said detector are coupled within said housing in a way which holds all of said elements in registration with one another.

6. A sensor as in claim 1, wherein said substrate is a substrate formed of a quartz.

7. A sensor as in claim 1, wherein said quartz substrate is less than a 1000 microns on each side.

8. A sensor as in claim 6, wherein said quartz substrate has a first surface with said first and second diffractive optical elements formed thereon and a second surface with diverging fringes which is placed in an area of light collection.

9. A method of measuring particles, comprising:  
placing a first surface of a transparent substrate into contact with a source of particles;

illuminating said particles with a laser via a diffractive optical element on a first surface of said

substrate and receiving scattered light from said particles via a second diffractive element on said first surface; and monitoring said received light to determine information about said particles.

5

10. A method as in claim 9, wherein said diffractive elements are formed by depositing PMMA on the surface of the substrate.

10

11. A method as in claim 9, wherein said substrate is formed of quartz.

12. A method as in claim 9, further comprising forming alignment marks on opposite sides of the substrate.

15

13. A method as in claim 12, wherein said alignment mark are formed as positive structures on one side, and lack of positive structures on the other side.

20

14. An integrated shear stress sensor, comprising:  
a housing;  
a laser diode coupled to said housing in a location to emit light from a top of said housing;



a sensing element, formed by a transparent substrate, having a first surface adjacent said laser diode to receive illumination therefrom and a second surface adjacent a top portion of said housing to sense particle movement; and

5 an optical sensor, also coupled to said housing, coupled adjacent to said substrate to receive collected light therefrom.

15. A sensor as in claim 14, wherein said first  
10 surface of said substrate includes two diffractive optical elements, a first optical element receiving said laser beam from said laser beam, and a second of said optical elements receiving collected light.

15 16. A sensor as in claim 15, wherein said diffractive optical elements are formed from PMMA layers on the substrate.

17. A sensor as in claim 14, further comprising  
20 optical slits on the second side of the substrate forming a fringe pattern in an area of said second side of said substrate, said fringe pattern interfering with said particles.

18. A sensor as in claim 14, wherein said optical sensor includes an avalanche photodiode.

19. A method of sensing particles, comprising:

5 illuminating particles with a photodiode via a series of slits which form a fringe pattern; and

detecting interference with said fringe pattern as detecting particle flow.

10 20. A method as in claim 19 wherein said detecting comprises detecting shear stress.

21. A method as in claim 19, wherein said detecting comprises detecting particle size.

15 22. A method as in claim 19, wherein said illuminating comprises forming two beams, and recombining said two beams to form said fringe pattern.

20 23. A method as in claim 22, wherein said two beams are formed by a laser producing two output beams.

24. A method as in claim 22, wherein said two beams are formed by a single grating with a blocked part.

25. A method as in claim 19, wherein said detecting comprises detecting light in two locations, and determining a phase shift therebetween.

5

26. A method of determining particle size, comprising:

forming an output of a laser;

interfering said output of said laser along two

10 separate paths with a third laser beam, at a location where said particle size is to be measured; and

using said interference to measure the size of the particle.

15 27. A method as in claim 26, wherein said using comprises detecting a phase shift between two separated receptors, which receive scattered light from said location.

20 28. A method as in claim 26, further comprising guiding the laser along two separate paths on a substrate; forming a grating on the substrate which causes the laser to follow said paths; and

detecting a particle above said substrate based on interference caused by said grating.

29. A method as in claim 26, further comprising  
5 locating a plurality of photodetectors in respective locations where they can sense interference of said laser.

30. A sensor system comprising:  
a substrate;  
10 a laser, mounted on said substrate to produce two outputs;  
gratings, located in said two directions, to modify said laser beam and produce another beam in a area of a particle whose characteristics are to be detected; and  
15 a detector, using an interference between said two beams to determine said characteristics of said particle.

31. A system as in claim 30, wherein said laser produces outputs in two different directions.

20

32. A system as in claim 30, wherein said laser produces a single output which is separated.

33. A system as in claim 30, further comprising photodetectors, mounted on said substrate to detect scattered light therefrom.

5 34. A system as in claim 30, further comprising photodetectors mounted above said substrate.

35. A particle sensor, comprising:

a semiconductor substrate;

10 a laser element, mounted on said semiconductor substrate, and producing at least one diverging beam;

a fringe producing element, producing a fringe in an area of a particle having characteristics to be measured; and

15 a detector, detecting scattered light from said fringe and said particles, and determining said characteristics of said particle from said scattered light.

36. A sensor as in claim 35, further comprising a  
20 single substrate, including a diffractive optical element placed to receive the beam, a scattering element which scatters light from the beam based on particles being detected, and a second diffractive element receiving scattered light.

37. A system as in claim 4, further comprising a semiconductor substrate, and wherein said laser and said detector are on the same semiconductor.

ABSTRACT

Integrated sensors are described using lasers on  
substrates. A first sensor forms a laser beam and uses a  
quart substrate to sense particle motion by interference of  
5 the particles with a defraction beam caused by a laser  
beam. A second sensor uses gradings to produce an  
interference.

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e. Features believed to be new

1. The integrated optical design of the miniature shear stress probe resulting in an integrated and self contained probe.
2. The design of the micro-shear stress sensor resulting in an extremely small, simple and rugged optical design.
- 3.

f. Close or related patents

5,199,298 4,866,098 5,052,228

g. Publications disclosing invention, including manuscripts in preparation

White paper prepared by the authors entitled "Development of a laser Doppler shear stress sensor".

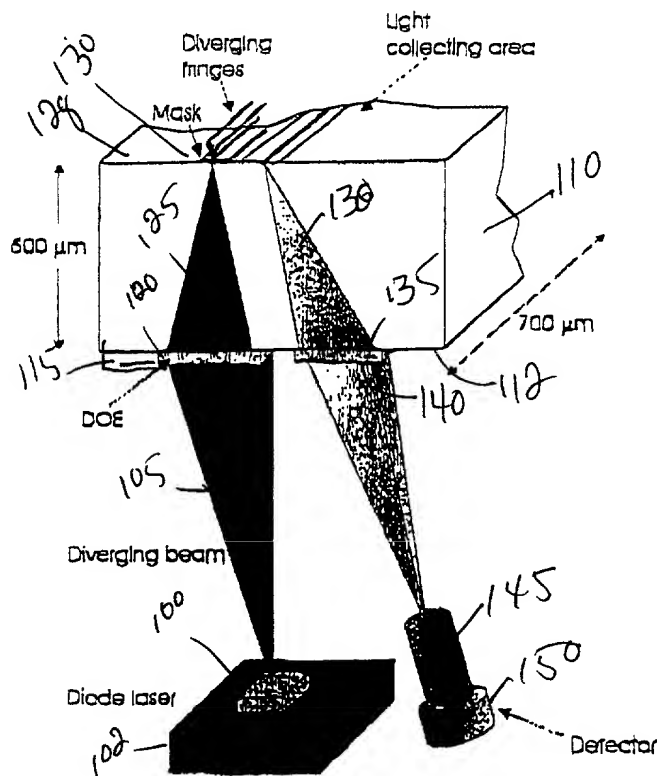


Figure 1. Schematic of the shear stress sensor.



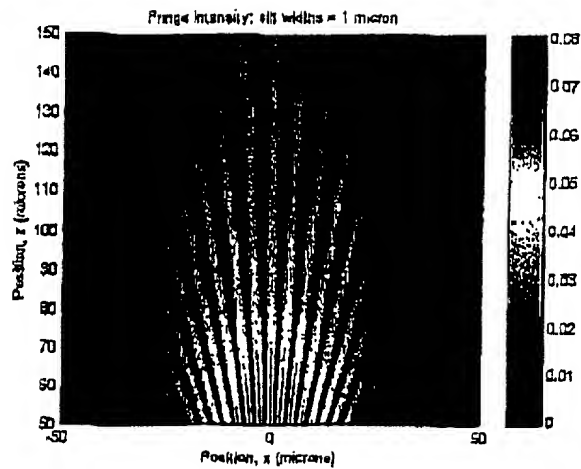


Figure 2. Fringe pattern distribution formed by the shear stress sensor optical assembly.

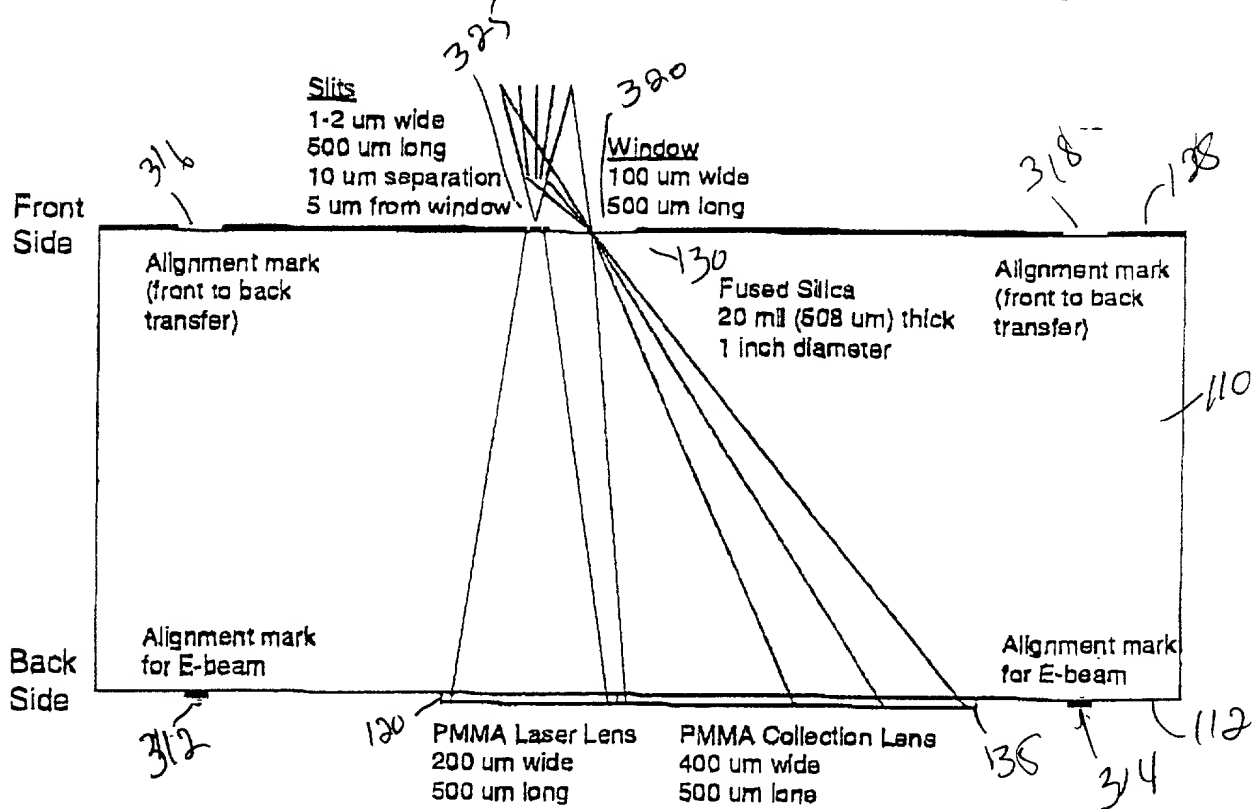


Figure 3. Fabrication sequence.

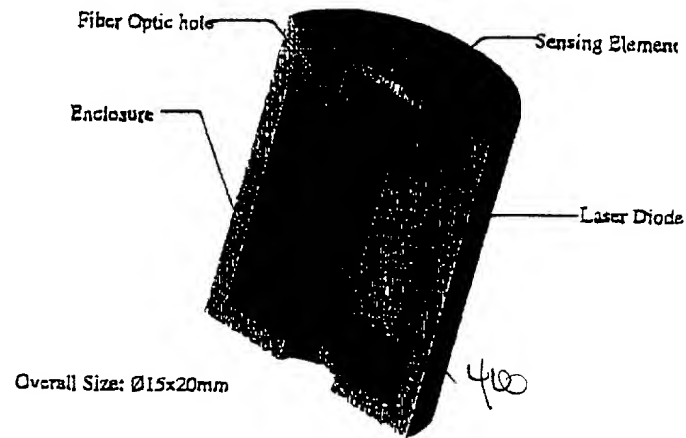


Figure 4. Shear stress sensor assembly.

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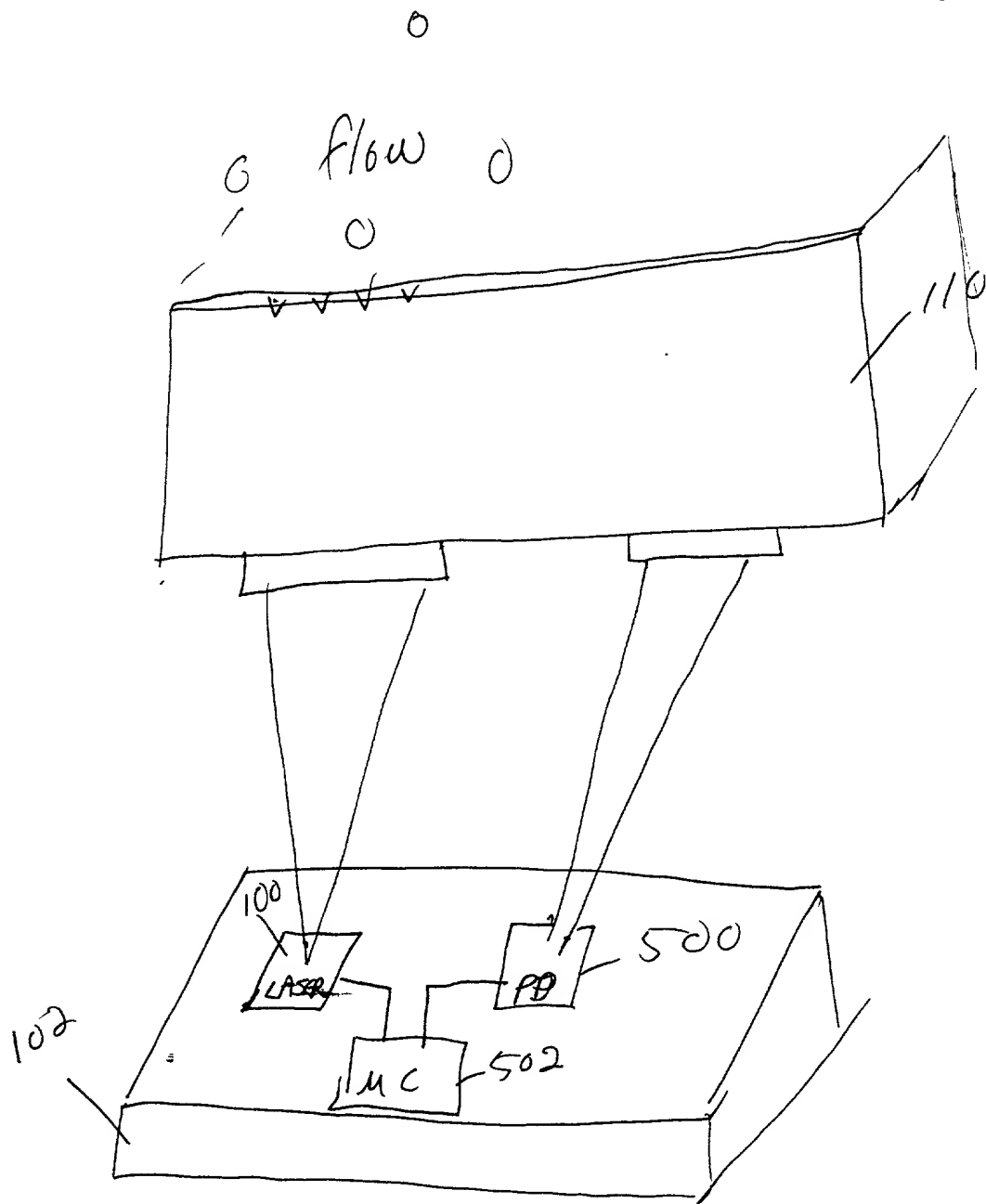
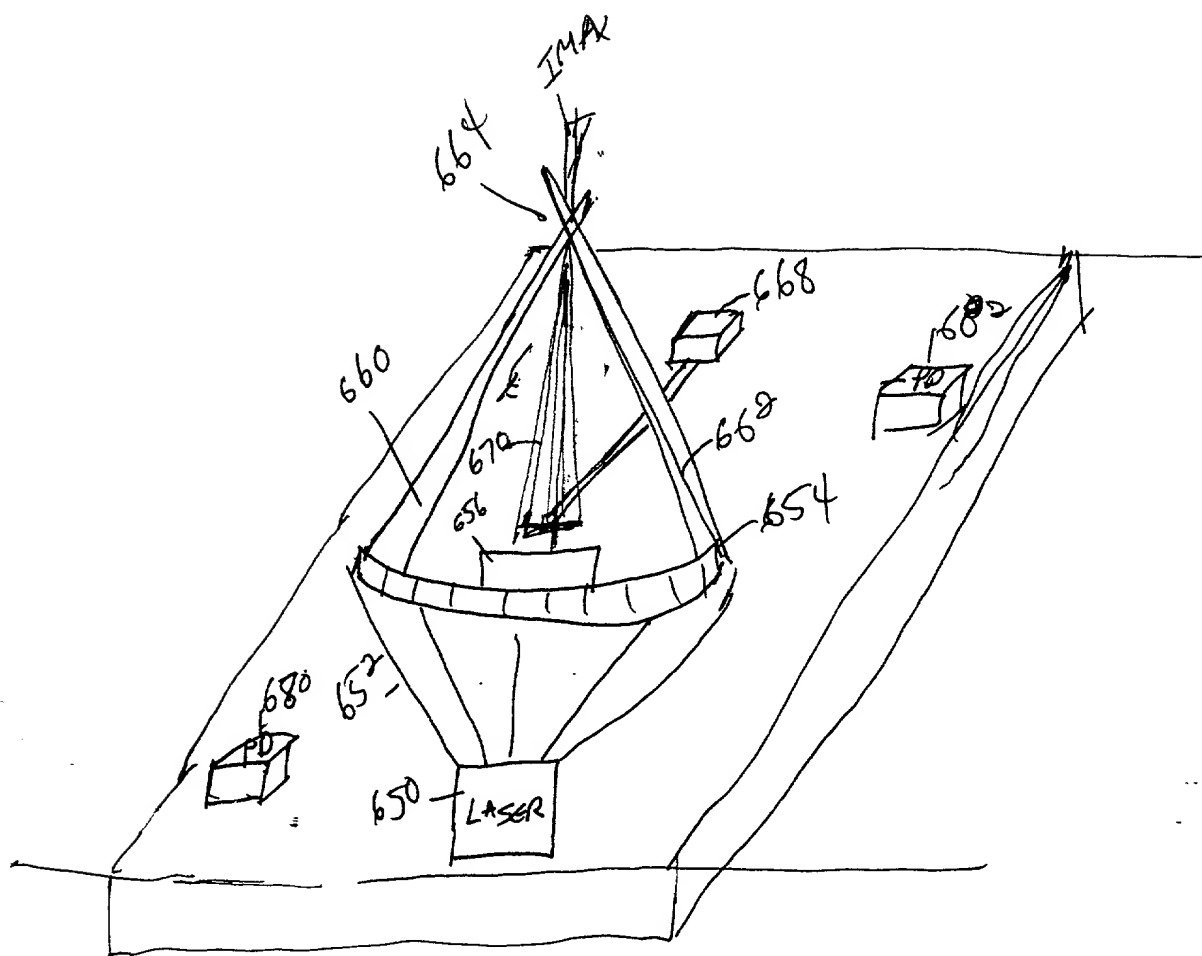


FIG 5



FIG 6B



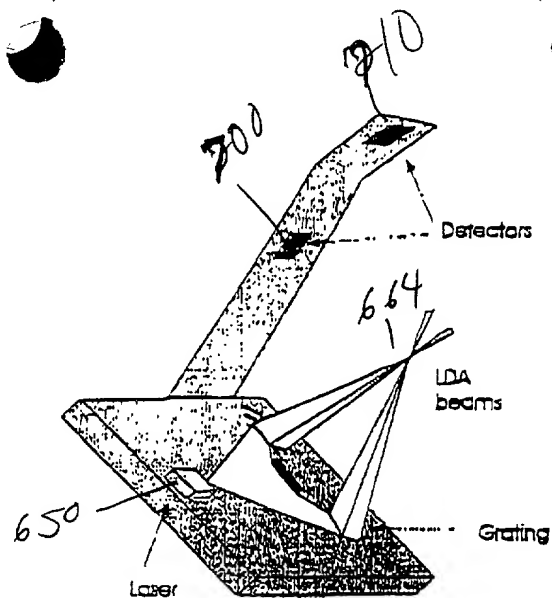


Figure 8. Particle sizing device using phase Doppler technique.

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